

(12) **United States Patent**
Raberg

(10) **Patent No.:** **US 9,207,292 B2**
(45) **Date of Patent:** **Dec. 8, 2015**

- (54) **MAGNETORESISTIVE DEVICE AND METHOD FOR MANUFACTURING THE SAME**
- (75) Inventor: **Wolfgang Raberg**, Sauerlach (DE)
- (73) Assignee: **Infineon Technologies AG**, Neubiberg (DE)
- (*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 450 days.
- (21) Appl. No.: **13/019,510**
- (22) Filed: **Feb. 2, 2011**
- (65) **Prior Publication Data**
- US 2012/0194180 A1 Aug. 2, 2012
- (51) **Int. Cl.**
- G01R 33/09** (2006.01)
B82Y 25/00 (2011.01)
G11C 11/00 (2006.01)
G01R 33/02 (2006.01)
G01R 33/025 (2006.01)
G11B 5/66 (2006.01)
- (52) **U.S. Cl.**
- CPC **G01R 33/093** (2013.01); **B82Y 25/00** (2013.01); **G01R 33/098** (2013.01); **G01R 33/02** (2013.01); **G01R 33/025** (2013.01); **G11B 5/66** (2013.01); **G11C 11/00** (2013.01)
- (58) **Field of Classification Search**
- CPC G01R 33/093; G01R 33/09; G01R 33/098; G01R 33/07
- USPC 324/252, 228, 207.21
- See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,623,867	A	11/1986	Lundquist et al.	
6,219,205	B1	4/2001	Yuan et al.	
6,368,706	B1 *	4/2002	Iwasaki	B82Y 10/00 257/E43.004
6,436,526	B1 *	8/2002	Odagawa	B82Y 10/00 257/E27.005
6,633,158	B1 *	10/2003	Shen	G01D 5/2515 324/207.13

6,642,714	B2 *	11/2003	Kobayashi	B82Y 25/00 324/225
6,664,784	B1 *	12/2003	Hayashi	B82Y 10/00 324/252
7,301,334	B2 *	11/2007	Shen	H01H 36/002 257/421
7,382,642	B2 *	6/2008	Boeve	G11C 11/15 365/158
2003/0173957	A1 *	9/2003	Shen	G01D 5/2515 324/207.26
2004/0121185	A1 *	6/2004	Fukuzawa	B82Y 10/00 472/815
2004/0248327	A1	12/2004	Onaka	
2006/0061916	A1 *	3/2006	Li	B82Y 10/00 360/324.11
2008/0116885	A1	5/2008	Van Zon et al.	
2008/0238420	A1 *	10/2008	Haratani	B82Y 25/00 324/252
2009/0046398	A1 *	2/2009	Werth	B82Y 25/00 324/252
2009/0058413	A1	3/2009	Kraemer et al.	

(Continued)

FOREIGN PATENT DOCUMENTS

DE	3883146	T2	3/1994
DE	602005005620	T2	7/2008

(Continued)

OTHER PUBLICATIONS

Robert E. Fontana, Jr., Process Complexity of Magnetoresistive Sensors: A Review, IEEE Transactions on Magnetics, vol. 31, No. 6, Nov. 1995, 2579-2584.*

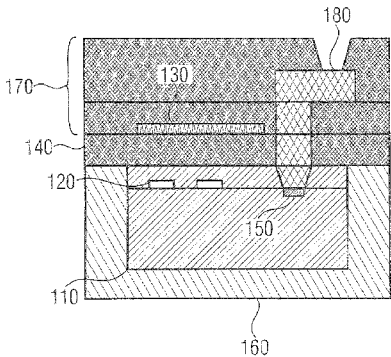
(Continued)

Primary Examiner — Jermele M Hollington
Assistant Examiner — Christopher McAndrew
(74) *Attorney, Agent, or Firm* — Eschweiler & Associates, LLC

(57) **ABSTRACT**

A magnetoresistive device includes a carrier, an xMR-sensor, a magnetic layer formed above an active xMR-region of the xMR-sensor and an insulating layer arranged between the xMR-sensor and the magnetic layer.

13 Claims, 13 Drawing Sheets



(56)

References Cited

U.S. PATENT DOCUMENTS

2009/0219018 A1* 9/2009 Shimazawa G01R 33/1207
324/210
2009/0294882 A1* 12/2009 Sterling G01R 33/072
257/427
2010/0045285 A1 2/2010 Ohmori et al.

FOREIGN PATENT DOCUMENTS

DE 112008001414 T5 4/2010
JP S57131078 A 8/1982

JP S5816580 A 1/1983
JP S59169187 A 9/1984
JP H03154389 A 7/1991
JP H07270508 A 10/1995
JP 2002094140 A 3/2002
JP 2004103780 A 4/2004
JP 2005285207 A 10/2005
WO 2008088021 A1 1/2008

OTHER PUBLICATIONS

Non Final Office Action Dated Oct. 6, 2015 U.S. Appl. No. 14/848,852.

* cited by examiner

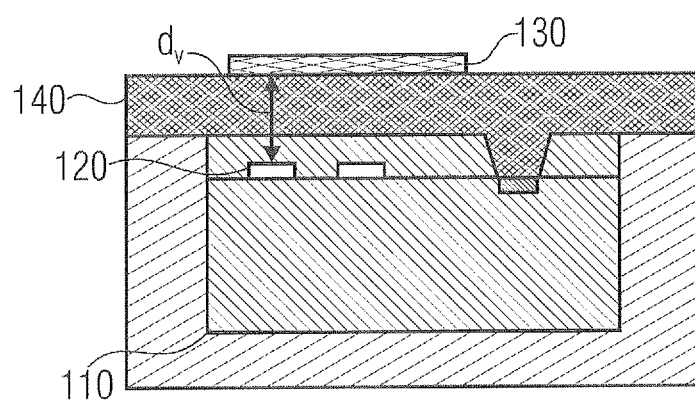
100

FIG 1

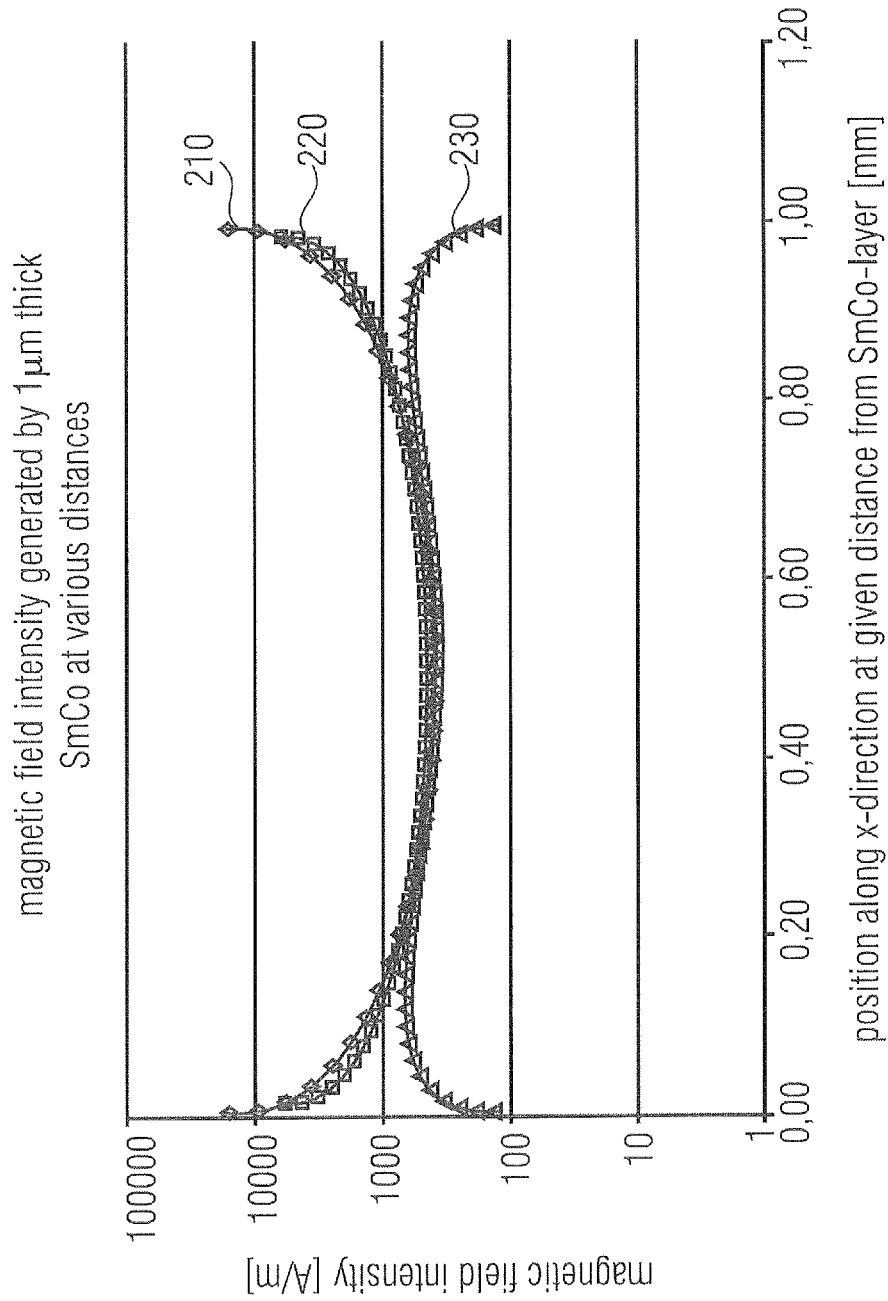


FIG 2

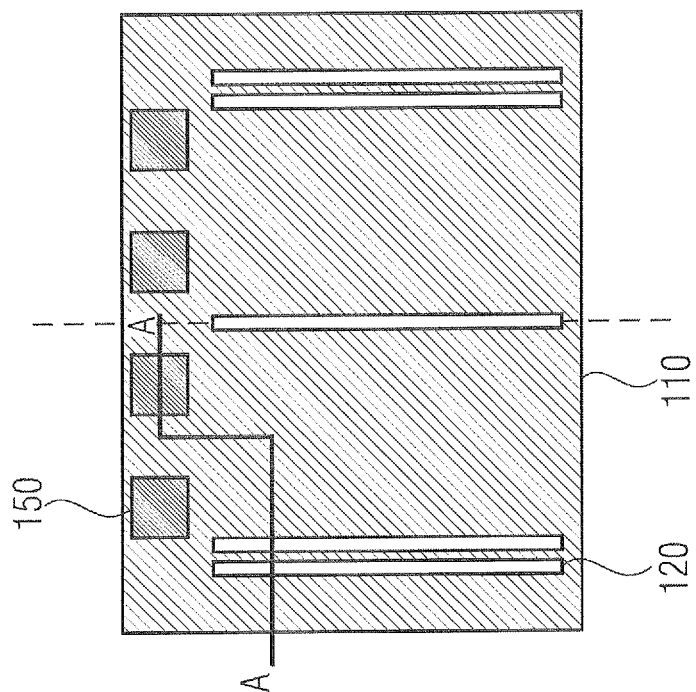


FIG 3A

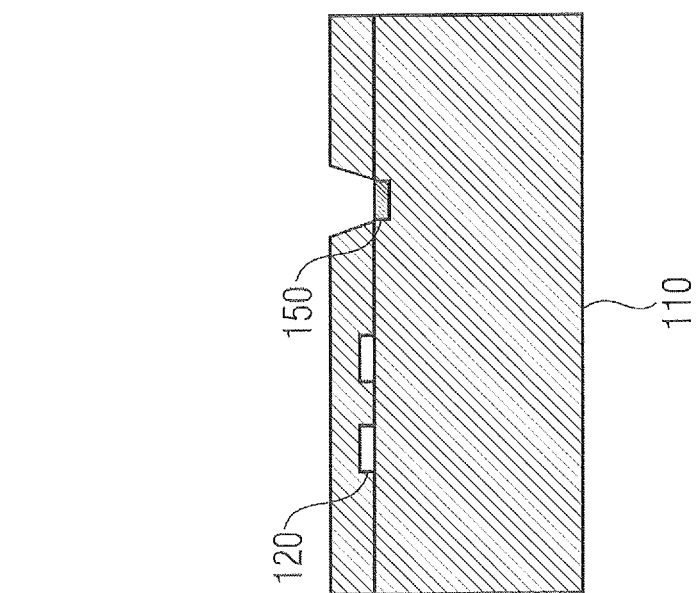


FIG 3B

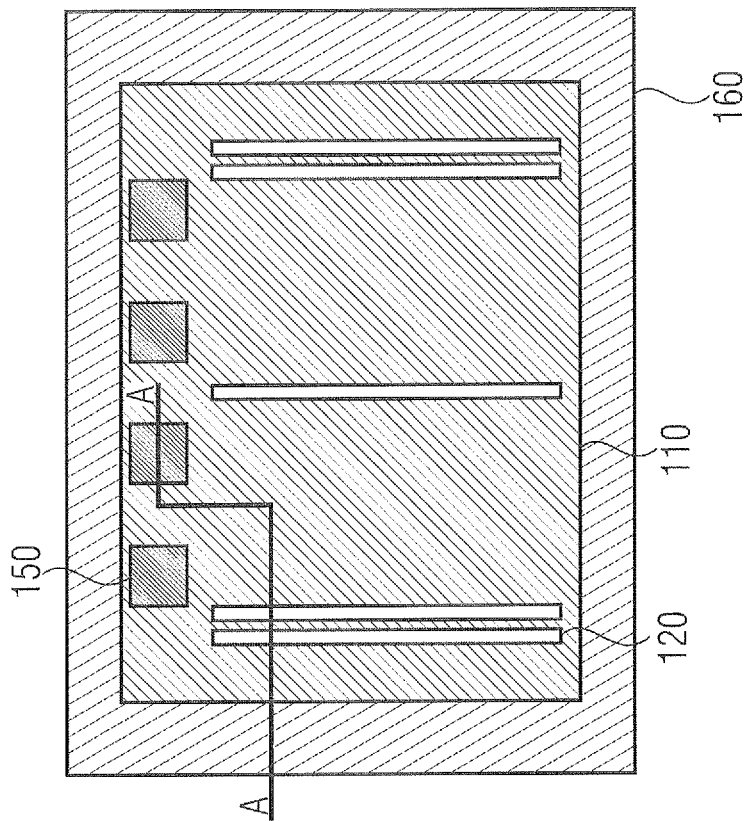


FIG 4B

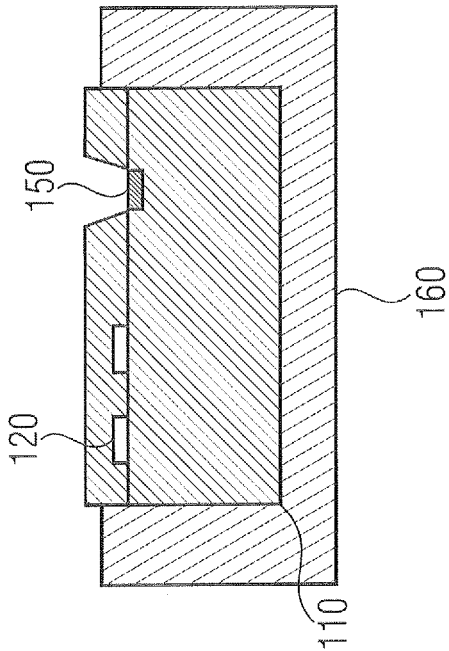


FIG 4A

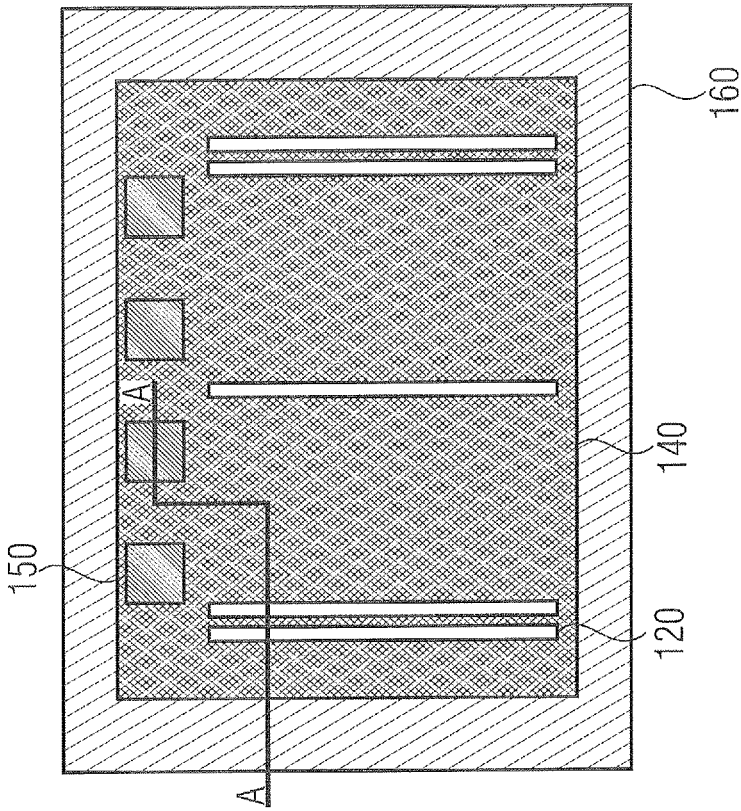


FIG 5B

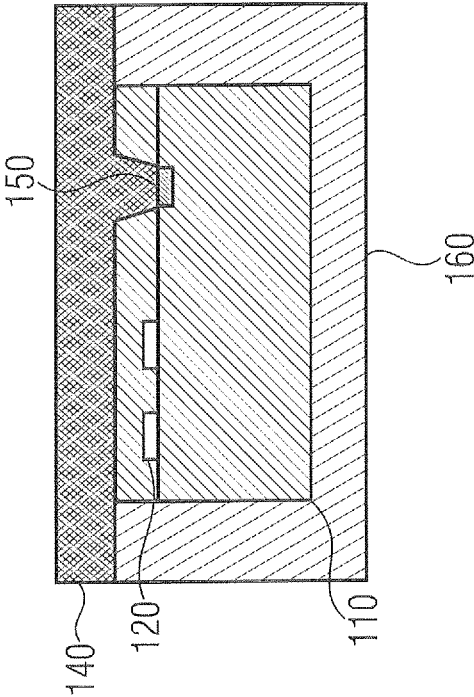


FIG 5A

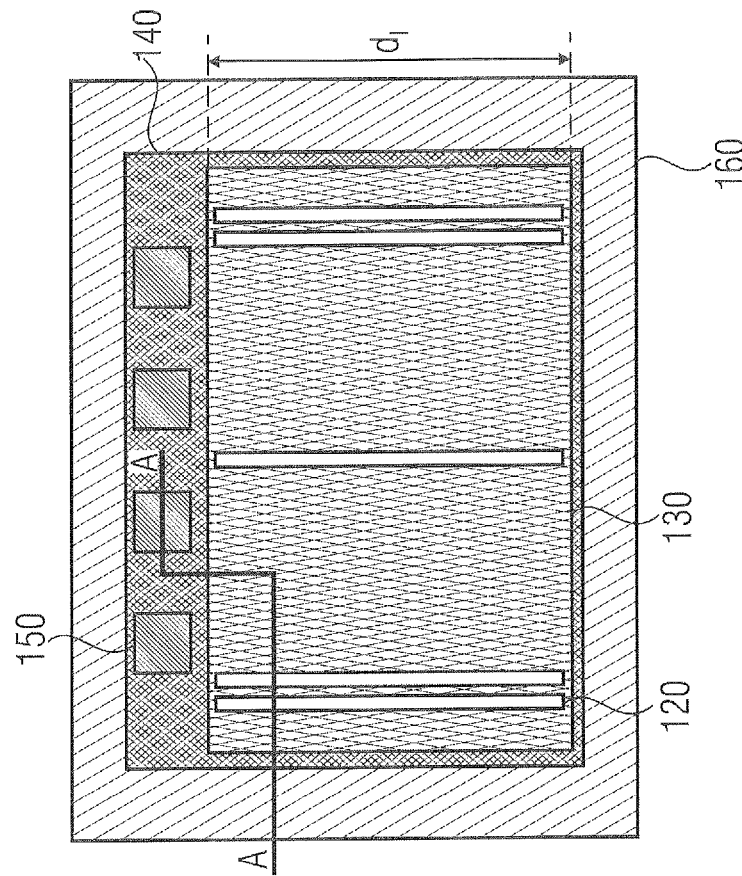


FIG 6B

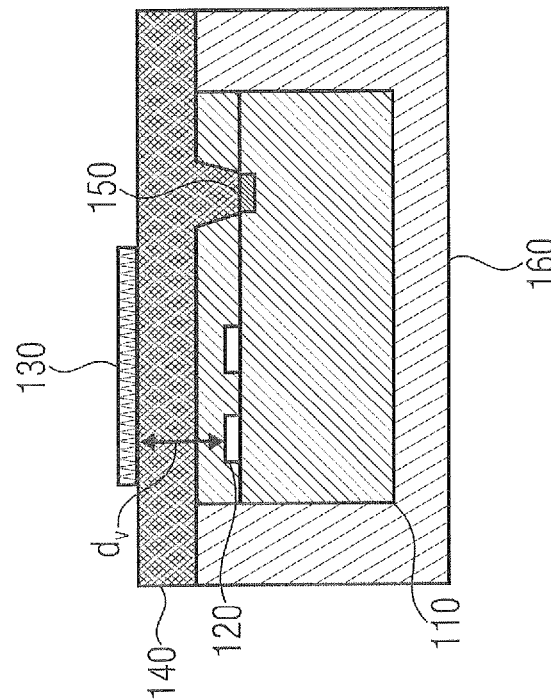


FIG 6A

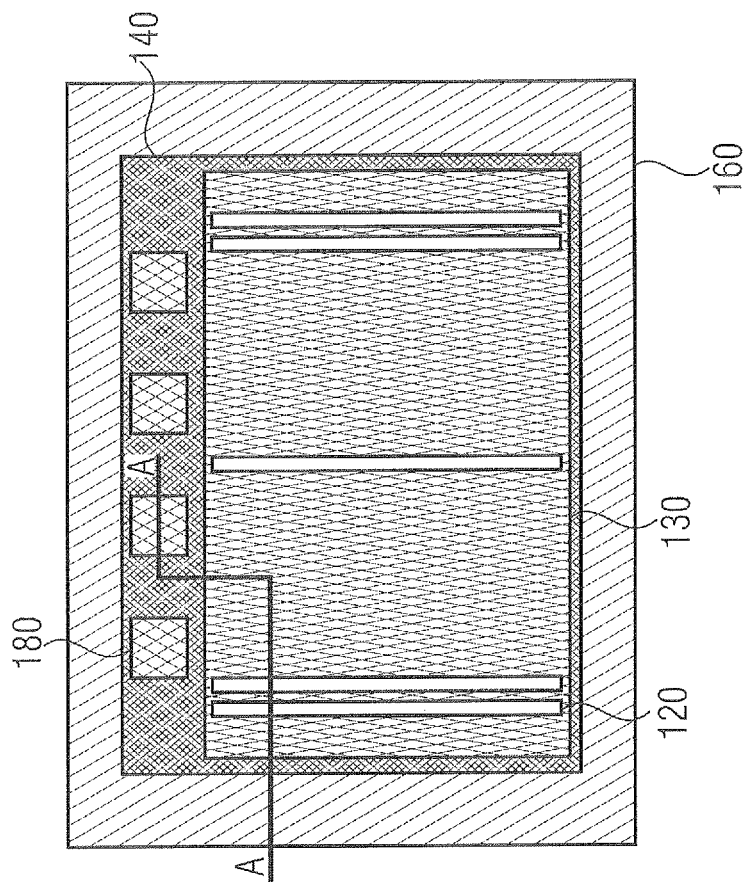


FIG 7B

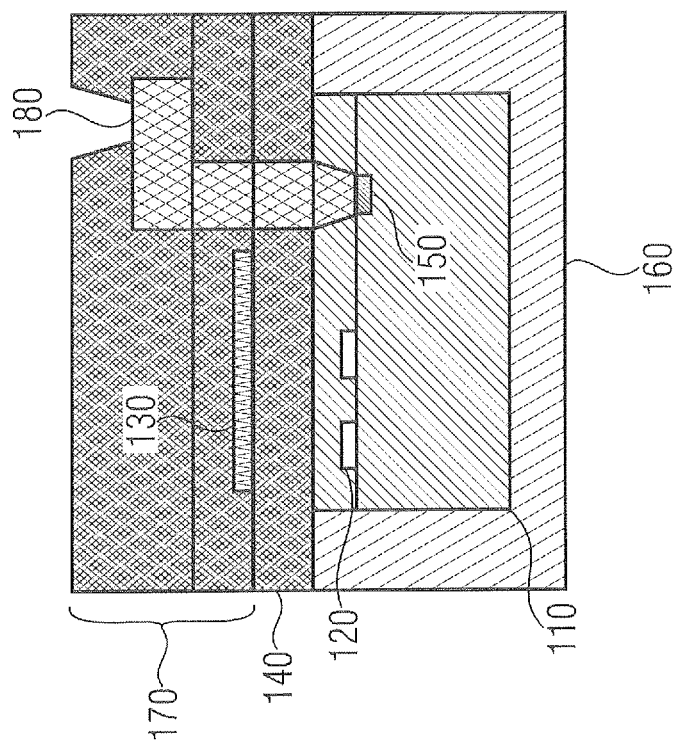


FIG 7A

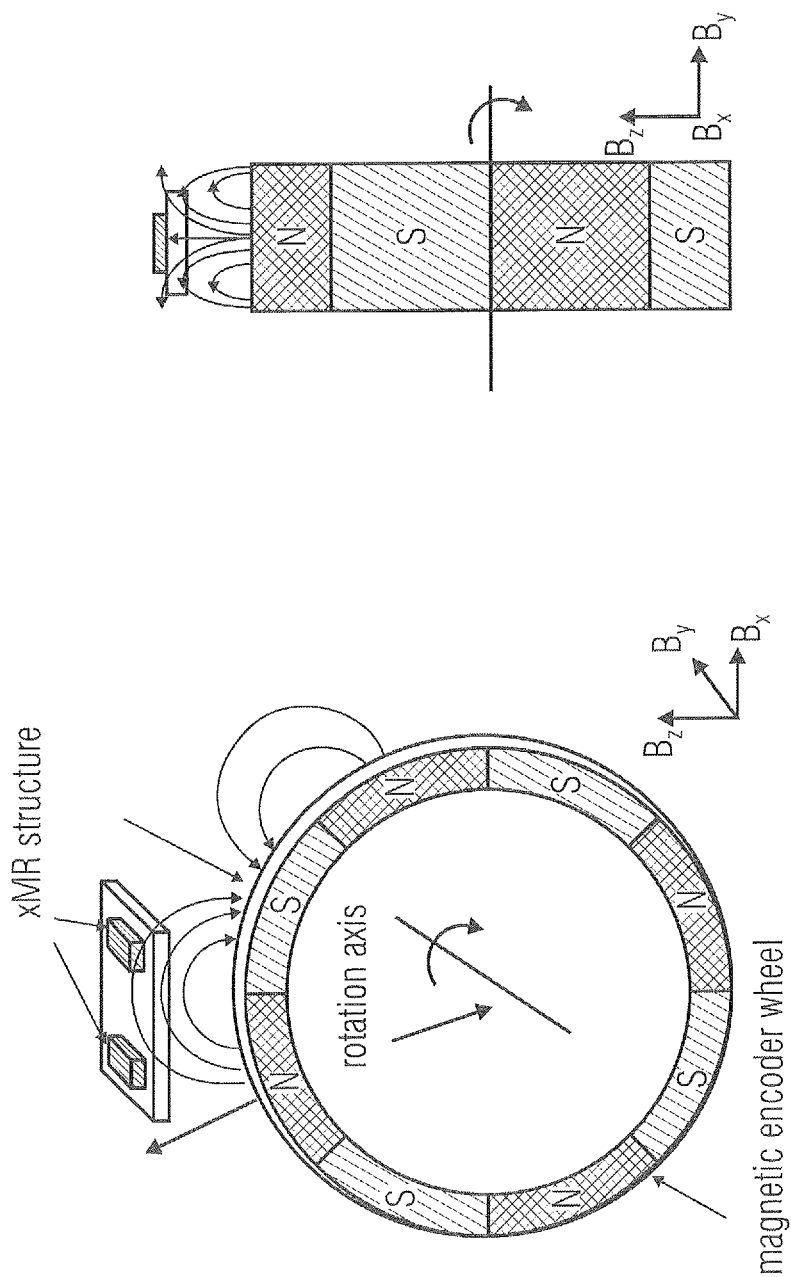


FIG 8A

FIG 8B

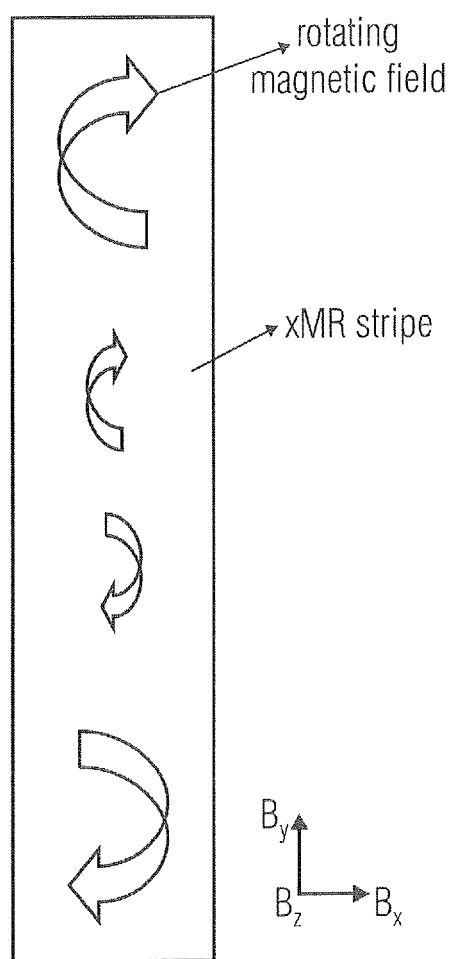


FIG 9

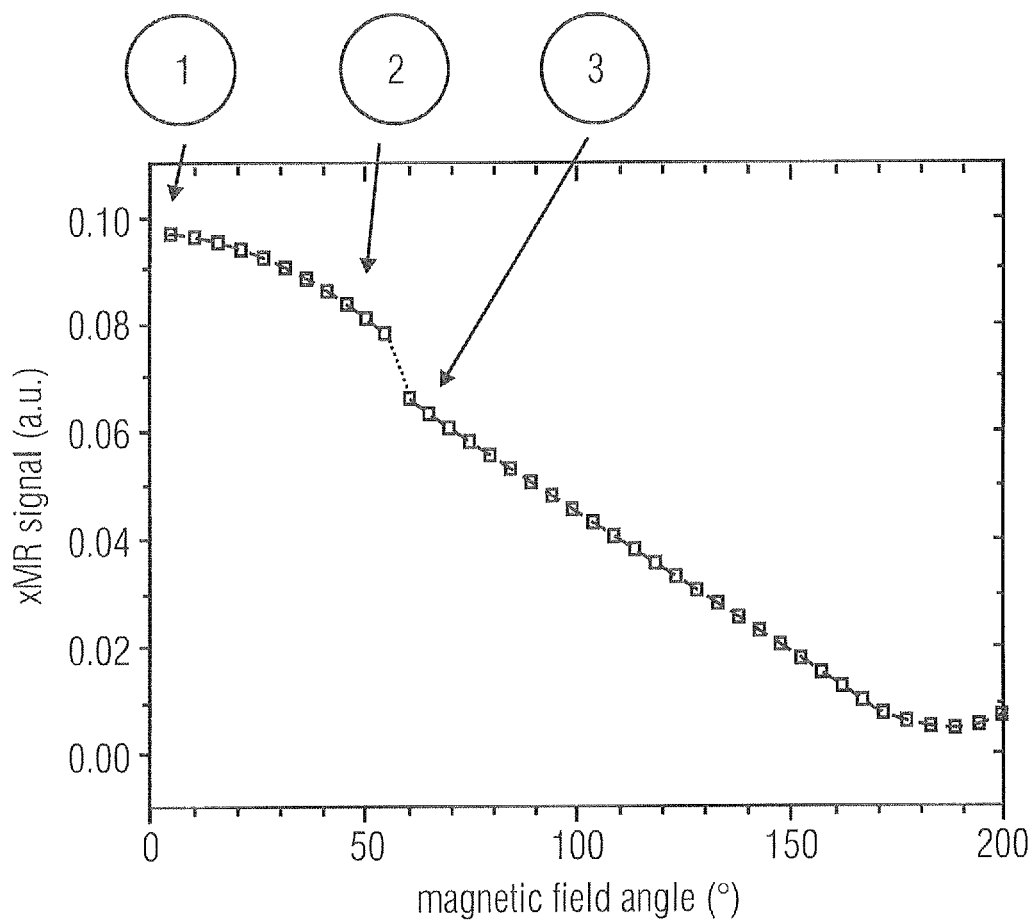


FIG 10

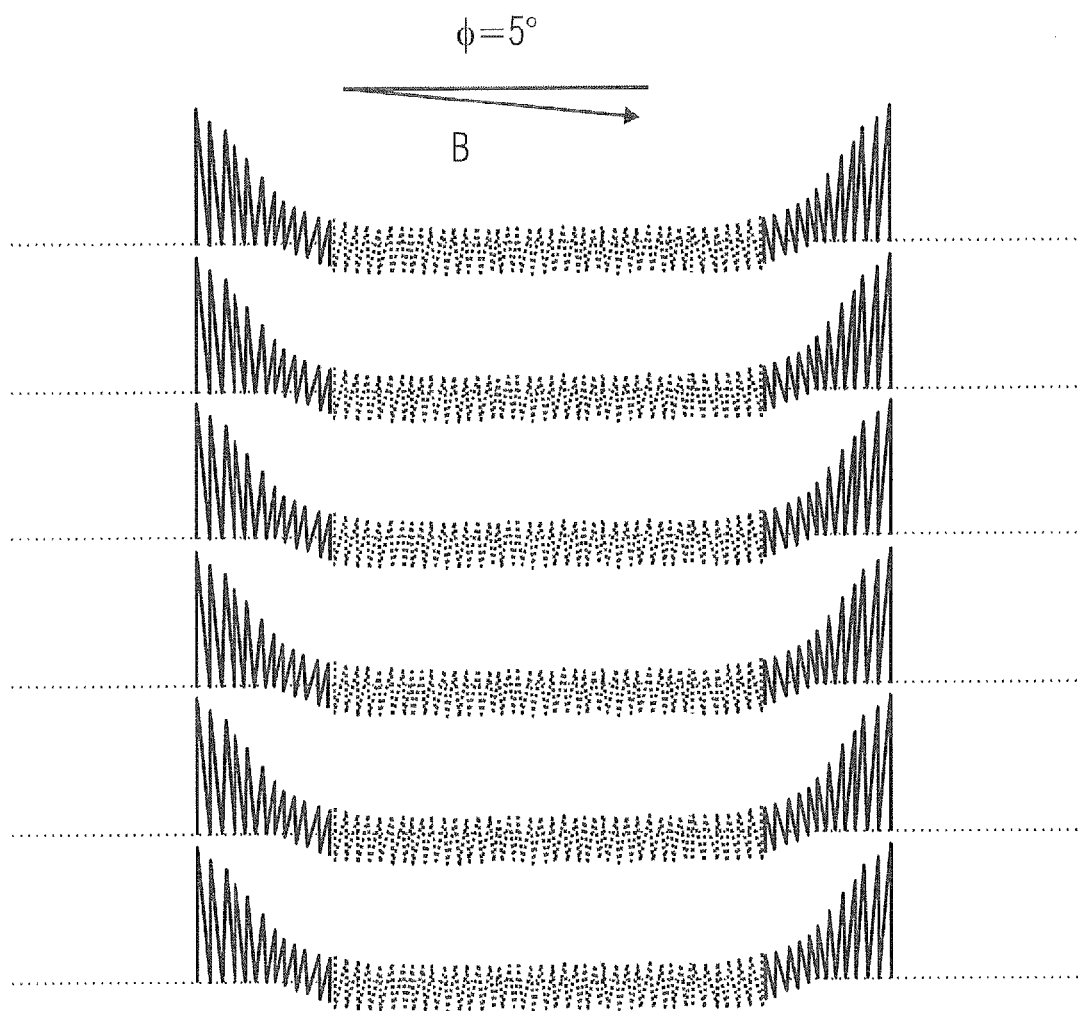
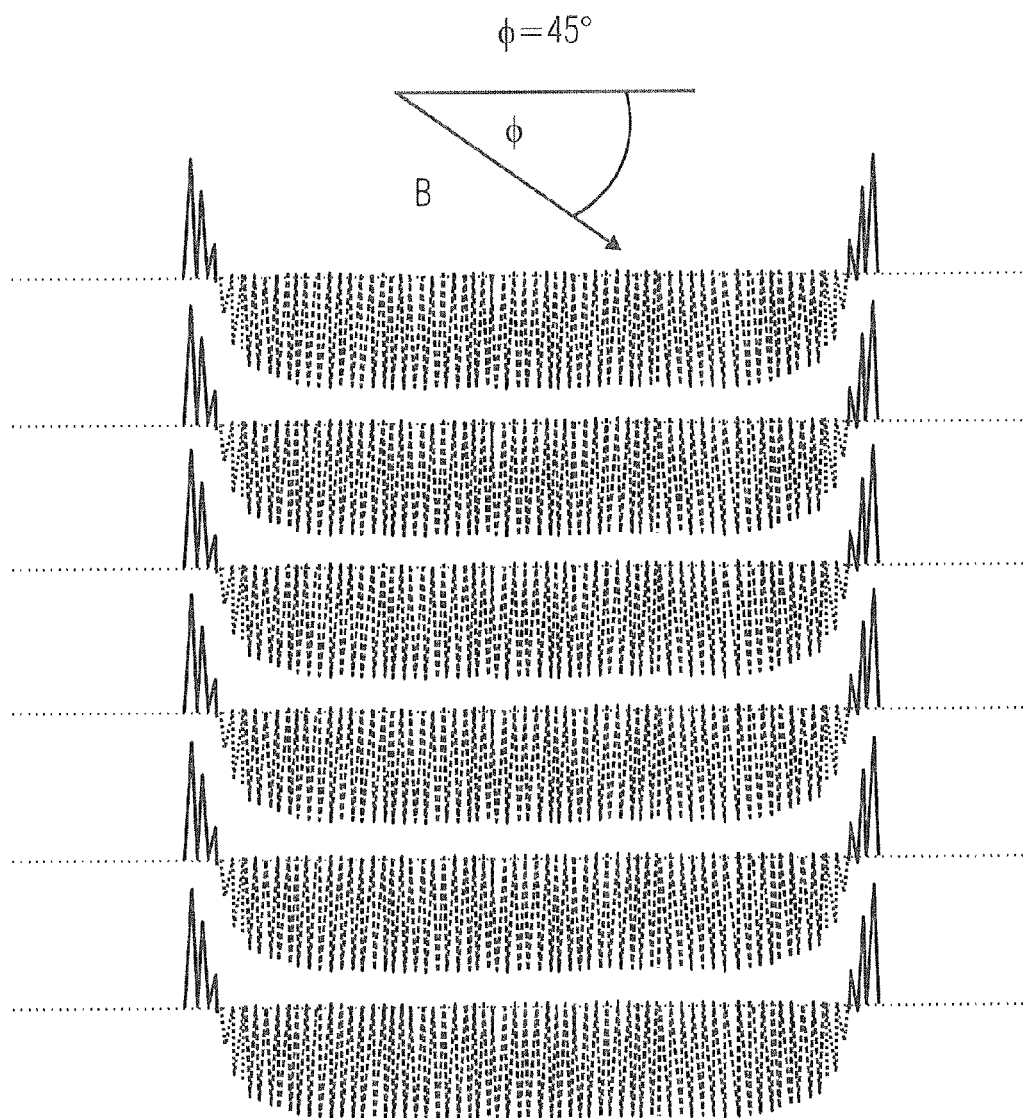


FIG 11A



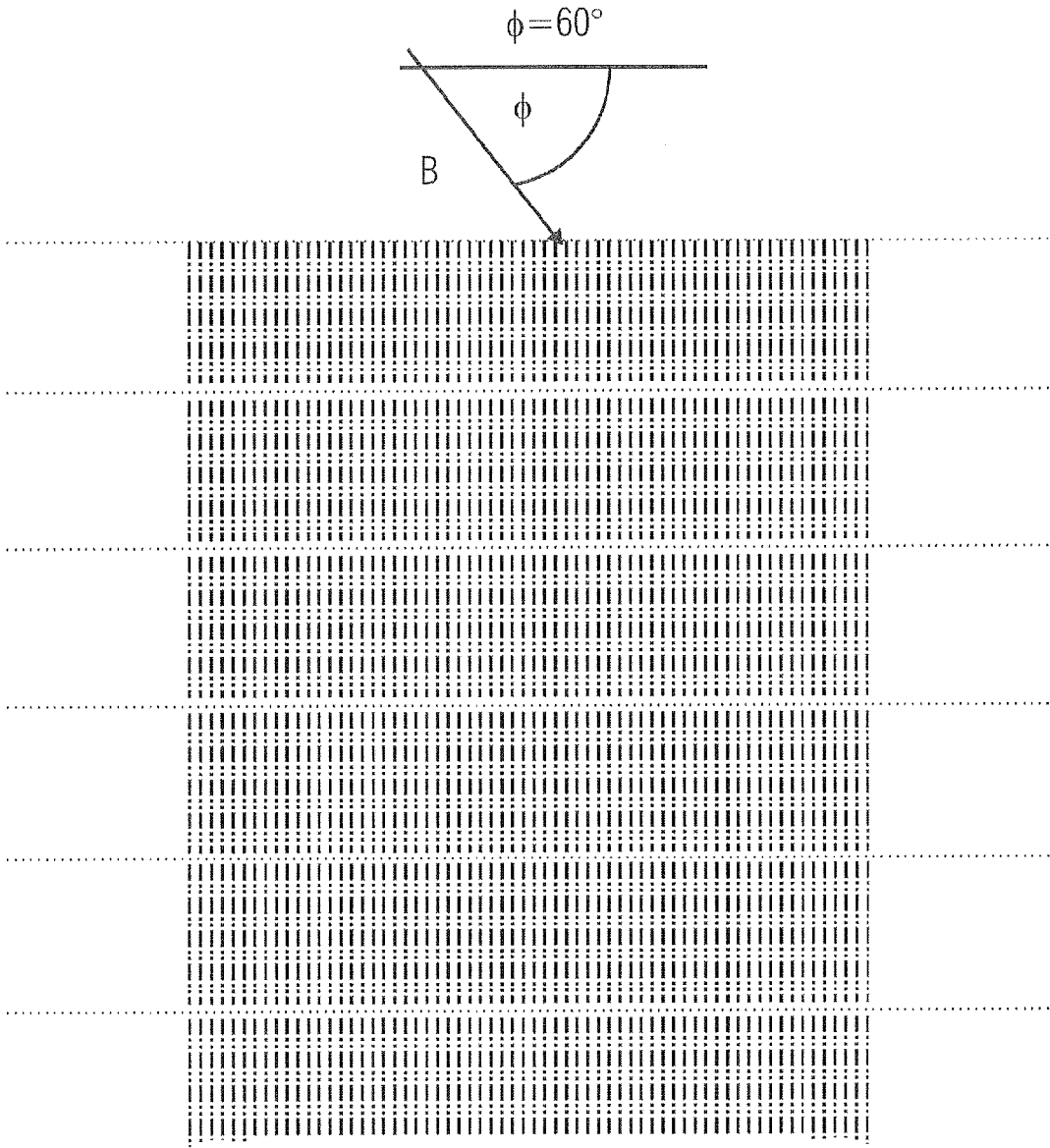


FIG 11C

1

MAGNETORESISTIVE DEVICE AND METHOD FOR MANUFACTURING THE SAME

FIELD

The invention is directed to a magnetoresistive device and a method for manufacturing the same. Further embodiments of the invention relate to magnetoresistive sensors, which are based on xMR technology, that may be employed in rotational speed sensor applications.

BACKGROUND

Today, speed sensors based on magnetoresistive devices including xMR structures are commonly used for rotational speed sensor applications. Such xMR based speed sensors are employed, for example, with a magnetic pole wheel as a transducer wheel. The magnetoresistive devices based on xMR technology may include xMR structures such as anisotropic magnetoresistance (AMR) structures, giant magnetoresistance (GMR) structures, or tunnel magnetoresistance (TMR) structures.

SUMMARY

Embodiments of the invention provide a magnetoresistive device, comprising a carrier, and an xMR-sensor situated on the carrier. The device further comprises a magnetic layer formed above an active xMR-region of the xMR-sensor, and an insulating layer arranged between the xMR-sensor and the magnetic layer.

Embodiments of the invention provide a magnetoresistive device, comprising a carrier, an xMR-sensor situated on the carrier that is based on an anisotropic magnetoresistance (AMR) effect, a giant magnetoresistance (GMR) effect, or a tunnel magnetoresistance (TMR) effect. The device further comprises a hard magnetic layer formed above an active xMR-region of the xMR-sensor, and an insulating layer arranged between the xMR-sensor and the hard magnetic layer. The hard magnetic layer is configured to provide a bias magnetic field for the active xMR-region of the xMR-sensor from above, and a vertical distance between the xMR-sensor and the hard magnetic layer is smaller than a lateral dimension of the hard magnetic layer.

Embodiments of the invention provide a magnetoresistive device, comprising an xMR-sensor, and means for providing a bias magnetic field for an active xMR-region of the xMR-sensor from a position above the xMR-sensor.

Embodiments of the invention provide a method for manufacturing a magnetoresistive device. The method comprises providing an xMR-sensor, and forming a magnetic layer above an active xMR-region of the xMR-sensor. In one embodiment, the xMR-sensor and the magnetic layer are integrated together to form an integrated circuit type device.

Embodiments of the invention provide a method for manufacturing a magnetoresistive device. The method comprises providing an xMR-sensor based on an anisotropic magnetoresistance (AMR) effect, a giant magnetoresistance (GMR) effect, or a tunnel magnetoresistance (TMR) effect, and forming a hard magnetic layer above an active xMR-region of the xMR-sensor. In addition, the method comprises arranging an insulating layer between the xMR-sensor and the hard magnetic layer, wherein the step of arranging the insulating layer is performed before the step of forming the hard magnetic layer above the active xMR-region of the xMR-sensor.

2

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows a schematic cross-sectional view of a magnetoresistive device according to an embodiment of the present invention;

FIG. 2 shows a graph of an example magnetic field intensity generated at the location of an xMR-sensor of the embodiment of the magnetoresistive device in accordance with FIG. 1;

FIG. 3a shows a schematic cross-sectional view of an embodiment of an xMR-wafer present after an FE-(Front-End) process and grinding;

FIG. 3b shows a schematic top view of the embodiment of the xMR-wafer in accordance with FIG. 3a;

FIG. 4a shows a schematic cross-sectional view of an embodiment of a manufacturing part of a magnetoresistive device after reconstitution;

FIG. 4b shows a schematic top view of the embodiment of the manufacturing part of the magnetoresistive device in accordance with FIG. 4a;

FIG. 5a shows a schematic cross-sectional view of an embodiment of a manufacturing part of a magnetoresistive device after deposition of a first dielectric layer;

FIG. 5b shows a schematic top view of the embodiment of the manufacturing part of the magnetoresistive device in accordance with FIG. 5a;

FIG. 6a shows a schematic cross-sectional view of an embodiment of a manufacturing part of a magnetoresistive device after deposition and patterning of a hard magnetic material;

FIG. 6b shows a schematic top view of the embodiment of the manufacturing part of the magnetoresistive device in accordance with FIG. 6a;

FIG. 7a shows a schematic cross-sectional view of an embodiment of a manufacturing part of a magnetoresistive device after patterning of a redistribution metal, deposition of a final dielectric layer and an opening;

FIG. 7b shows a schematic top view of the embodiment of the manufacturing part of the magnetoresistive device in accordance with FIG. 7a;

FIG. 8a shows a view on a BX/BZ plane of a schematic setup of an embodiment of an xMR speed sensor in a pole wheel configuration;

FIG. 8b shows a view on a By/Bz plane of the embodiment of the xMR speed sensor in accordance with FIG. 8a;

FIG. 9 shows a schematic illustration of a magnetic field rotation across an xMR stripe length when a stripe is positioned in the center of the pole wheel depicted in FIG. 8a;

FIG. 10 shows a graph of a simulated xMR response upon rotation of a rotating magnetic field, illustrating a characteristic discontinuity;

FIG. 11a shows a bird's view on simulated magnetization regions of the free layer of an xMR stripe for a magnetic field angle of 5° corresponding to point 1 in FIG. 10;

FIG. 11b shows a bird's view on simulated magnetization regions of the free layer of an xMR stripe for a magnetic field angle of 45° corresponding to point 2 in FIG. 10; and

FIG. 11c shows a bird's view on simulated magnetization regions of the free layer of an xMR stripe for a magnetic field angle of 60° corresponding to point 3 in FIG. 10.

DETAILED DESCRIPTION

Many of today's xMR based speed sensors are employed with a magnetic pole wheel as a transducer wheel.

The xMR structures are usually narrow stripes with a homogeneous width of <2 μm in order to provide a defined

sensitivity by the shape anisotropy. To achieve a reasonable xMR resistance in the range of 10 kOhms, the stripe is several 100 μm long. The transducer pole wheels have only a limited thickness/axial width and therefore, the magnetic signal field is not homogeneous over the whole stripe length. With growing (axial) distance from the pole wheel center, the B_y component increases and is phase shifted by 180° between the lower and upper half of the pole wheel (see, e.g., FIGS. 8a, 8b and 9). In combination with a B_x component which is phase shifted by $\pm 90^\circ$ to the individual B_y components, this results in a rotation of the magnetic field vector.

The shape anisotropy results in a different behavior of the magnetizations over the stripe width: whereas the domains in the center can follow quite easily an external magnetic field, the magnetization regions at the edges are much more stable. FIGS. 11a, 11b, and 11c show a bird's eye view on the simulated magnetization of the free layer (i.e. sensor layer) of the xMR stack upon exposure to an external rotating field with $B_x=B_y=8\text{ mT}$. The rotation starts at $\phi=0^\circ$ with the magnetic field pointing to the right. At $\phi=5^\circ$ (point 1 in FIG. 10) the center magnetization region can follow whereas the edge regions keep their magnetization in the initial direction in the upper half space. A further clockwise rotation ($\phi=45^\circ$ corresponding to point 2 in FIG. 10) leads to a generation of 180° domain walls between the magnetizations of the stripe center and the edge. At around $\phi=60^\circ$ rotation angle (corresponding to point 3 in FIG. 10) the force on the edge regions is strong enough to turn their magnetization direction along the external field. This switching process is reflected in a discontinuity in the resistance characteristic (see FIG. 10). FIG. 10 shows an example graph of a simulated xMR response upon exposure to a rotating magnetic field ($B=8\text{ mT}$). Referring to FIG. 10, a discontinuity in the characteristic can be observed between field angles of 55° and 60° . The field angle where the switching occurs depends on the field conditions (B_y/B_x ratio) of the rotating field vector and the shape anisotropy and therefore, the stripe width.

The discontinuity in the output signal can heavily affect the interpretation of the signal (jitter, pulse lost, etc.)

According to the prior art, methods for creating a uni-axial bias magnetic field for stabilizing the direction of free layer magnetization exist. By using such a bias field, discontinuities in the output signal generated by rotating free layer magnetization can be prevented or at least reduced. Known methods to create such a bias field employ, for example, the use of a hard magnetic bias material at the edges of the sensor layer, the exchange biasing of the free layer with a natural antiferromagnet, or the mounting of a bias magnet to the back of the sensor.

In particular, the use of a hard magnetic bias material at the edges of the sensor layer can be used only for very short devices, while the exchange biasing of the free layer with a natural antiferromagnet typically creates a rather large bias field. In addition, the method of mounting a bias magnet to the back of the sensor is rather complex and increases the cost of manufacturing the device and increases its size.

Therefore, a need exists for an improved concept of a magnetoresistive device, which, on the one hand, allows for a compact and flexible structure and, on the other hand, allows for a less complex and cost-effective manufacturing of the same.

Embodiments of the invention provide a compact and flexible structure that can be achieved if a magnetic layer is formed above an active xMR-region of the xMR-sensor. By this measure, disadvantages in terms of complexity, cost and size may be overcome, thereby realizing an improved concept of a compact and flexible magnetoresistive device.

FIG. 1 shows a schematic cross-sectional view of a magnetoresistive device 100 according to an embodiment of the present invention. As shown in FIG. 1, the magnetoresistive device 100 comprises a carrier 110, an xMR-sensor 120, a magnetic layer 130 and an insulating layer 140. Here, the magnetic layer 130 is formed above an active xMR-region of the xMR-sensor 120. In addition, the insulating layer 140 is arranged between the xMR-sensor 120 and the magnetic layer 130.

The xMR-sensor 120 of the magnetoresistive device 100 can, for example, be based on an anisotropic magnetoresistance (AMR) effect, a giant magnetoresistance (GMR) effect, or a tunnel magnetoresistance (TMR) effect. It can be seen in FIG. 1 that the magnetoresistive device 100 may also comprise two or more xMR-sensors which are arranged next to each other on the carrier 110. The two or more xMR-sensors can be used in one embodiment to detect a gradient of an externally applied magnetic field.

The carrier 110 of the magnetoresistive device 100 can, for example, be a semiconductor substrate made of silicon.

In the embodiment of FIG. 1, the magnetic layer 130 of the magnetoresistive device 100 is configured to provide a bias magnetic field for the active xMR-region of the xMR-sensor 120 from above. This essentially can be achieved by forming the magnetic layer 130 above the active xMR-region of the xMR-sensor 120. The presented measure allows for an improved functionality of the magnetoresistive device and provides an easier usage, handling and manufacturing of the same.

Thus, according to the embodiment of FIG. 1, the magnetic layer is configured to provide a bias magnetic field for the active xMR-region of the xMR-sensor from above.

According to embodiments of the present invention, the magnetic layer 130 of the magnetoresistive device 100 may be configured as a hard magnetic layer or a soft magnetic layer. The hard magnetic layer, for example, can be made of a hard magnetic material comprising SmCo, hard ferrite or NdFeB. The soft magnetic layer, for example, can be made of a soft magnetic material exchange biased by a natural antiferromagnet.

Referring to the embodiment of FIG. 1, the vertical distance d_v between the xMR-sensor 120 and the magnetic layer 130 lies within a range of approximately 1 to 100 μm , preferably 3 to 10 μm . Because of this small vertical distance, the bias magnetic field provided by the magnetic layer 130 can be generated in direct vicinity to the xMR-sensor 120 of the magnetoresistive device 100.

According to further embodiments, the magnetic layer 130 is configured as a hard magnetic layer having a magnetization direction along the direction of the easy axis of the xMR-sensor 120. In this way, it can be insured that a bias magnetic field will be generated from the hard magnetic layer in the active xMR-region of the xMR-sensor 120 along the easy axis of the xMR-sensor 120.

In particular, the hard magnetic layer 130 can be provided with a magnetization, a thickness and a vertical distance d_v from the xMR-sensor 120 such that a strength of the bias magnetic field generated along the easy axis of the xMR-sensor 120 will be between approximately 2 and 10 mT.

As a consequence, the strength of the bias magnetic field generated along the easy axis of the xMR-sensor can be variably adjusted, so that a rotating free layer magnetization in the active xMR-region of the xMR-sensor can be avoided or at least minimized, thereby reducing discontinuities in the output signal of the xMR-sensor. It is pointed out here that the bias magnetic field to be generated along the easy axis of the xMR-sensor can be applied to stabilize the direction of the

5

free layer magnetization without having to increase the complexity, cost and size of the magnetoresistive device.

FIG. 2 shows a graph of an example magnetic field intensity generated at the location of an xMR-sensor of the embodiment of the magnetoresistive device in accordance with FIG. 1. In particular, three curves **210**, **220**, and **230** of the magnetic field intensity generated by a 1 μm thick SmCo-layer (hard magnetic layer) at various distances are shown in FIG. 2. The vertical axis of the graph represents the magnetic field intensity (1 mT~796 A/m), while the horizontal axis of the graph represents the position at a lateral direction or the x-direction at a given distance from the SmCo-layer. Here, the 1 μm thick SmCo-layer may correspond to the magnetic layer **130** of the magnetoresistive device **100** as shown in FIG. 1. The various distances associated with the different curves **210**, **220**, and **230** in the graph of FIG. 2 may correspond to different vertical distances d_v (e.g., 1 μm , 10 μm and 100 μm , respectively) between the xMR-sensor **120** and the magnetic layer **130** of the magnetoresistive device **100**. It can be seen clearly in FIG. 2 that the three curves **210**, **220**, and **230** of the magnetic field intensity are nearly identical within a range of approximately 0.2-0.8 mm, while they significantly deviate from each other outside of this range. It is to be noted that the magnetic field intensity is plotted with a logarithmic scale here. The characteristic behavior of the different curves **210**, **220**, and **230** shows that the generated magnetic field intensity is not influenced substantially by variations in the distance between the xMR-sensor and the magnetic layer. Therefore, the magnetoresistive device can be made robust against such variations in the distance.

Thus, referring to FIG. 2, the simulation shows little influence in the field intensity up to vertical distances d_v of 100 μm . In embodiments of the present invention, the vertical distance d_v is between approximately 1 to 100 μm , preferably between 3 to 10 μm .

According to further embodiments of the present invention, a method for manufacturing a magnetoresistive device may comprise the following steps. First, an xMR-sensor is provided. Then, a magnetic layer is formed above an active xMR-region of the xMR-sensor. Here, it is pointed out that the xMR-sensor may be provided on top of an CMOS circuitry in one embodiment, essentially representing an integrated sensor.

According to further embodiments, the method for manufacturing the magnetoresistive device may further comprise arranging an insulating layer between the xMR-sensor and the magnetic layer. Here, the step of arranging the insulating layer is performed before the step of forming the magnetic layer above the active xMR-region of the xMR-sensor.

Moreover, the magnetoresistive device obtained from the manufacturing process including the xMR-sensor, the magnetic layer and the insulating layer may correspond to the magnetoresistive device **100** including the xMR-sensor **120**, the magnetic layer **130** and the insulating layer **140**, respectively.

FIGS. 3a, 3b-7a, 7b show schematic cross-sectional views and corresponding top views of embodiments of manufacturing parts of a magnetoresistive device obtained after different steps in the manufacturing process.

Referring to FIGS. 3a, 3b-7a, 7b, the procedure for manufacturing the magnetoresistive device according to one embodiment of the present invention is briefly described in the following. Here, the cross-sectional views of FIGS. 3a-7a are taken along the lines A-A in FIGS. 3b-7b, while the top views of FIGS. 3b-7b shows the structures of FIGS. 3a-7a adjacent to each other.

6

First, an xMR-wafer or GMR-wafer is processed through the FE (Front-End) in a standard way and then thinned down. Thinning down the xMR-wafer can be achieved by a grinding process in one embodiment. As a starting point, the xMR-wafer after the FE-process and the grinding is obtained, is shown in FIG. 3a or 3b, respectively. In FIGS. 3a and 3b, the carrier **110**, such as an Si-chip including CMOS circuitry, and one or more xMR-sensors **120**, such as a GMR-sensor, are depicted. Moreover, an opening and a contact pad **150** may be provided onto or into the carrier **110**.

After this, in one embodiment the xMR-chips are singulated, placed on a foil and reconstituted to a wafer-like substrate using a mold compound. FIGS. 4a and 4b show the processing result after the reconstitution. In particular, a mold **160** is depicted in FIGS. 4a and b surrounding the carrier **110**.

After removal of the foil, an insulating layer **140** or dielectric layer is deposited on top of the passivation layer or photoimide with a thickness ranging between 3-10 μm . The processing result after deposition of the insulating layer **140** or the first dielectric layer with a thickness of e.g. 5 μm is depicted in FIG. 5a or 5b, respectively. As can be seen in FIGS. 5a and 5b, the insulating layer **140** covers the carrier **110** completely and extends within an area defined by an inner perimeter of the mold **160**. In other words, the step of arranging the insulating layer comprises depositing a dielectric layer having a thickness between 3 and 10 μm .

Subsequently, a magnetic layer **130** such as a hard magnetic layer made, e.g., of SmCo, NdFeB or hard ferrite is formed above the active xMR-region of the xMR-sensor **120** such that the field generated by this layer **130** at the location of the xMR-sensors **120** or xMR-elements is along the easy axis of the xMR-sensors or xMR-elements and has a strength of between 2 mT and 10 mT. This, for example, can be achieved by an SmCo layer with a thickness of approximately 3 μm . The processing result of a deposition and patterning of a hard magnetic material (e.g. a 3 μm thick hard magnetic SmCo-layer) is depicted in FIGS. 6a and 6b, respectively. It can be seen from FIGS. 6a and 6b that the magnetic layer **130** is formed above an active xMR-region of the xMR-sensor **120**, wherein a vertical distance d_v between the xMR-sensor **120** and the magnetic layer **130** is smaller than a lateral dimension of the magnetic layer **130**. As has been described with reference to FIG. 2, an advantage of such a configuration is that variations in the distance between the xMR-element and the hard magnetic layer have a negligible effect as long as the distance is small compared to the lateral dimension of the bias layer.

Thus, according to the embodiment described above, a vertical distance between the xMR-sensor and the magnetic layer is smaller than a lateral dimension of the magnetic layer. In this way, it is possible to avoid an influence of variations in the distance between the xMR-sensor and the magnetic layer on the performance reliability of the magnetoresistive device.

Following the formation of the magnetic layer **130** or bias layer, another dielectric layer, a redistribution metal layer and a final dielectric layer (structure **170**) are deposited. The processing result after patterning of the redistribution metal, deposition of a final dielectric layer (third ILD, Inter-Layer Dielectric) and an opening is shown in FIG. 7a or 7b, respectively. Referring to FIGS. 7a and 7b, an opening in the final dielectric layer and a via **180** filled, for example, with a metallic material are provided, thereby realizing an electrical contact with the pad **150**.

The example process flow described with reference to FIGS. 3a, 3b-7a, 7b can advantageously be used for manufacturing of a magnetoresistive device with a reduced process complexity, cost and size.

Embodiments of the present invention provide the advantage that discontinuities in the output signal generated by a rotating free layer magnetization can be prevented or at least reduced. Moreover, disadvantages in terms of process complexity, cost and size of the resulting sensor device can be avoided.

Embodiments of the present invention provide a concept for creating a uni-axial bias field along the easy axis of an xMR-sensor without significant costs added and without change of the final sensor device.

The present invention provides this concept by creating bias fields in the extreme vicinity of the xMR-sensor elements after finishing the standard wafer process of the integrated device. This vicinity can be achieved by employing a wafer level approach to create a magnetic layer or intermediate layer on the face side of the xMR-sensor, which contains, e.g. a thin hard magnetic material (electro-deposited or sputtered) or a soft magnetic layer, exchange biased by a natural anti-ferromagnet.

An advantage of the method according to an embodiment of the present invention is that the magnetic layer or intermediate layer (bias layer or biasing layer) allows one to create a magnetic bias field in direct vicinity to the sensor layer or free layer, thereby significantly reducing the amount of material needed.

Embodiments of the present invention also provide the advantage that the bias field can be tuned easily by varying the thickness of the (biasing) layer. In addition, variations in the distance between biasing layer and sensor have negligible influence. In embodiments of the present invention, no modification of the sensor element itself is required, so that no influence on the reliability of the device is to be expected.

The present invention provides a very cost-effective solution due to the application of semiconductor methodology. Embodiments of the present invention provide a design of a bias layer which easily can be changed via lithography.

As opposed to the prior art, it has been found that no significant changes to the integration process have to be made if the process is performed in the presented way. Embodiments of the present invention provide an add-on process flow that can be performed without consideration of the integration technology used for the sensor element itself and, specifically, for integrated CMOS and xMR-sensors.

Embodiments of the invention are not restricted in flexibility and efficiency and are advantageous in terms of complexity, cost and size.

In summary, the present invention is realized by utilizing a wafer level approach to create a biasing layer in direct vicinity to the xMR-elements. This can, for example, be achieved by adding a dedicated metallization level on top of the xMR-sensor wafer or by utilizing an eWLB (embedded Wafer Level Ball Grid Array) approach.

Although some aspects have been described in the context of an apparatus, it is clear that these aspects also represent a description of the corresponding method, where a block or device corresponds to a method step or a feature of a method step. Analogously, aspects described in the context of a method step also represent a description of a corresponding block or item or feature of a corresponding apparatus.

The above described embodiments are merely illustrative for the principles of the present invention. It is understood that modifications and variations of the arrangements and the details described herein will be apparent to others skilled in the art. It is the intent, therefore, to be limited only by the scope of the impending patent claims and not by the specific details presented by way of description and explanation of the embodiments herein.

The invention claimed is:

1. A magnetoresistive device, comprising:

a carrier;

an xMR-sensor formed on or in the carrier, the xMR-sensor based on an anisotropic magnetoresistance (AMR) effect, a giant magnetoresistance (GMR) effect, or a tunnel magnetoresistance (TMR) effect;

a hard magnetic layer distinct from the xMR-sensor and formed above an active xMR-region of the xMR-sensor; and

an insulating layer distinct from the xMR-sensor and arranged between the xMR-sensor and the hard magnetic layer,

wherein the hard magnetic layer is configured to provide a bias magnetic field in the active xMR-region of the xMR-sensor from a position above the xMR-sensor along the easy axis of the xMR-sensor, and

wherein a vertical distance between the xMR-sensor and the hard magnetic layer is smaller than a lateral dimension of the hard magnetic layer.

2. A method for manufacturing a magnetoresistive device, the method comprising:

providing an xMR-sensor on or in a carrier; and

forming a magnetic layer distinct from the xMR-sensor and above an active xMR-region of the xMR-sensor, wherein the magnetic layer and the xMR-sensor are integrated together to form an integrated circuit type device,

wherein the magnetic layer distinct from the xMR-sensor is configured to provide a bias magnetic field in the active xMR-region of the xMR-sensor from a position above the xMR-sensor along the easy axis of the xMR-sensor.

3. The method according to claim 2, further comprising:

arranging an insulating layer between the xMR-sensor and the magnetic layer, wherein the step of arranging the insulating layer is performed before forming the magnetic layer above the active xMR-region of the xMR-sensor.

4. The method according to claim 3, wherein arranging the insulating layer comprises depositing a dielectric layer having a thickness between 3 and 10 μm .

5. The method of claim 3, wherein a thickness of the insulating layer defines a vertical distance between the magnetic layer and the xMR-sensor, and wherein the vertical distance is smaller than a lateral dimension of the magnetic layer.

6. The method according to claim 2, wherein forming the magnetic layer comprises electrodepositing or sputtering the hard magnetic layer having a thickness of approximately 3 μm .

7. A method for manufacturing a magnetoresistive device, the method comprising:

providing an xMR-sensor on or in a carrier based on an anisotropic magnetoresistance (AMR) effect, a giant magnetoresistance (GMR) effect, or a tunnel magnetoresistance (TMR) effect;

forming a hard magnetic layer distinct from the xMR-sensor and above an active xMR-region of the xMR-sensor; and

arranging an insulating layer distinct from the xMR-sensor between the xMR-sensor and the hard magnetic layer, wherein arranging the insulating layer is performed before forming the hard magnetic layer above the active xMR-region of the xMR-sensor, and

wherein the magnetic layer distinct from the xMR-sensor is configured to provide a bias magnetic field in the

9

active xMR-region of the xMR-sensor from a position above the xMR-sensor along the easy axis of the xMR-sensor.

8. The method of claim 7, wherein the hard magnetic layer, the insulating layer and the xMR-sensor are integrated together to form an integrated circuit type device.

9. The method of claim 7, wherein a thickness of the insulating layer defines a vertical distance between the hard magnetic layer and the xMR-sensor, and wherein the vertical distance is smaller than a lateral dimension of the hard magnetic layer.

10. The magnetoresistive device of claim 1, wherein the magnetic layer comprises a hard magnetic layer, and wherein a magnetization direction of the hard magnetic layer is along a direction of an easy axis of the xMR-sensor such that a bias magnetic field is generated from the hard magnetic layer in the active xMR-region of the xMR-sensor along the easy axis of the xMR-sensor.

10

11. The magnetoresistive device of claim 1, the hard magnetic layer having a magnetization direction along a direction of an easy axis of the xMR-sensor such that a bias magnetic field is generated from the hard magnetic layer in the active xMR-region of the xMR-sensor along the easy axis of the xMR-sensor.

12. The method of claim 2, wherein the magnetic layer comprises a hard magnetic layer, and wherein a magnetization direction of the hard magnetic layer is along a direction of an easy axis of the xMR-sensor such that a bias magnetic field is generated from the hard magnetic layer in the active xMR-region of the xMR-sensor along the easy axis of the xMR-sensor.

13. The method of claim 7, the hard magnetic layer having a magnetization direction along a direction of an easy axis of the xMR-sensor such that a bias magnetic field is generated from the hard magnetic layer in the active xMR-region of the xMR-sensor along the easy axis of the xMR-sensor.

* * * * *